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Investigation of Flexibility and Freeze-Thaw Tolerance of Cu – Water HPs for Space Applications

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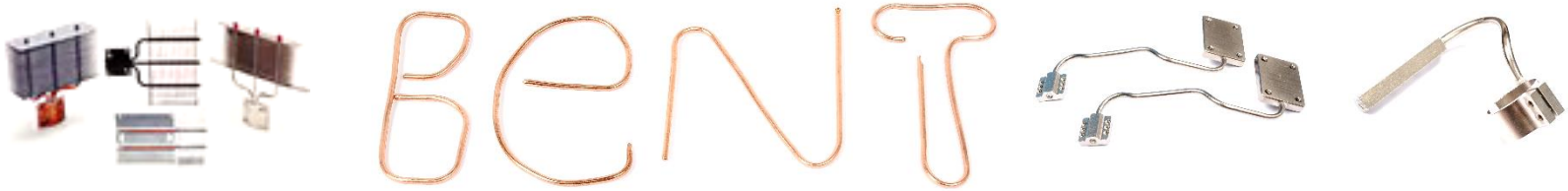
Thermal Management Solutions

Introduction

- Copper – water HPs have been used in various cooling applications including space applications.

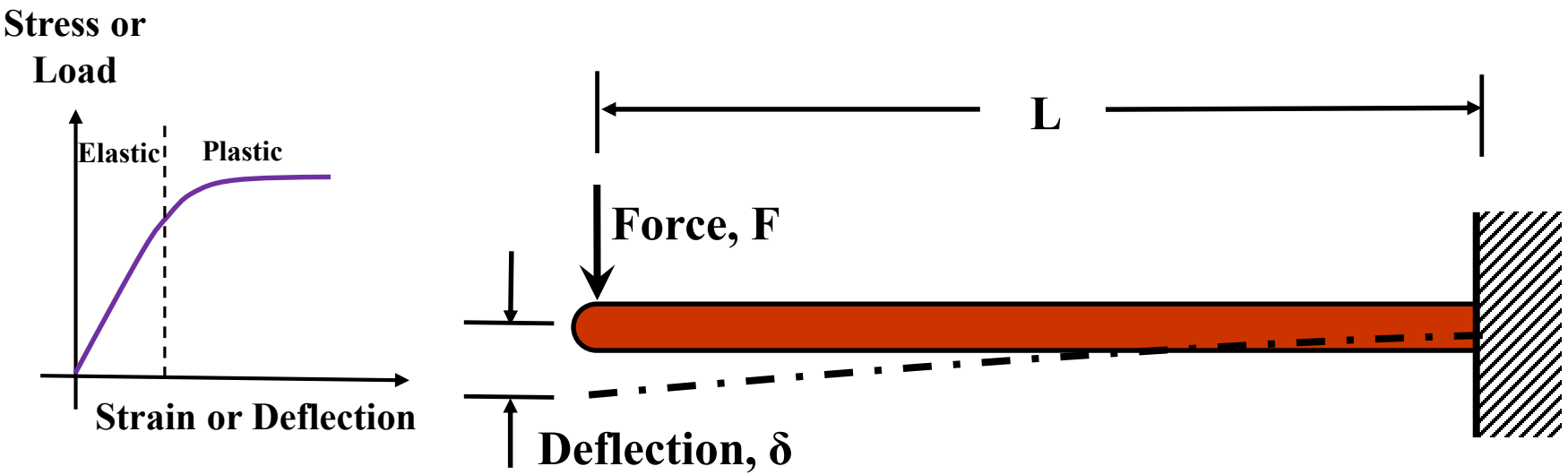
- Copper – water HPs can be bent into various shapes:



- Do they have enough flexibility for a particular application?
  - This presentation provides a guideline on how to estimate flexibility of copper – water HPs.

- Copper – water HPs can be made to survive freezing.
  - Presented results on freeze-thaw cycling of copper – water HPs.

Cantilever Beam Deflection

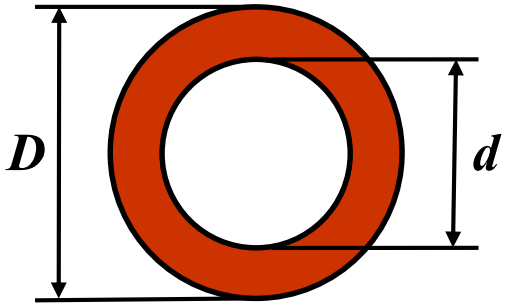


$$\delta = \frac{FL^3}{3EI}$$ (elastic deflection of the free end)

$$\phi = \frac{FL^2}{2EI}$$ (angle of deflection in radians)

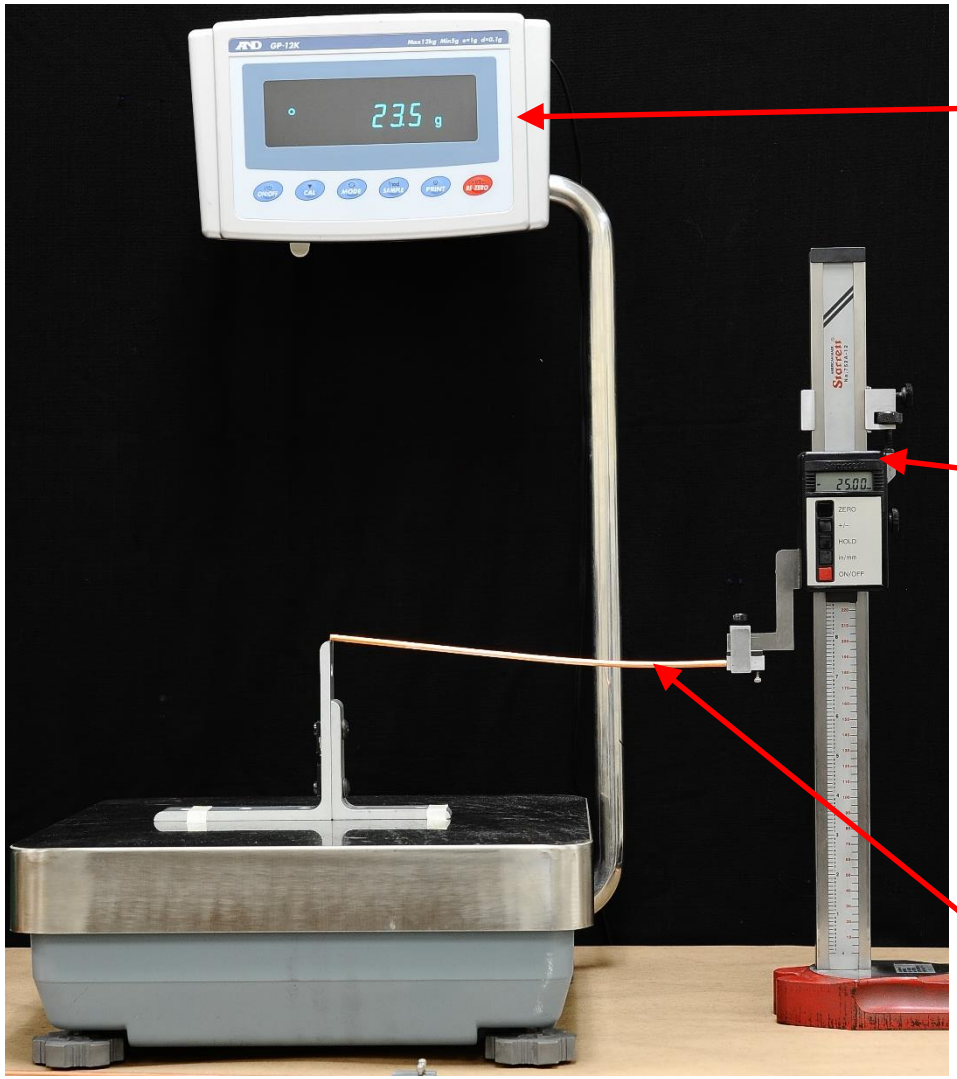
E – module of elasticity

I – area moment of inertia of the beams cross section

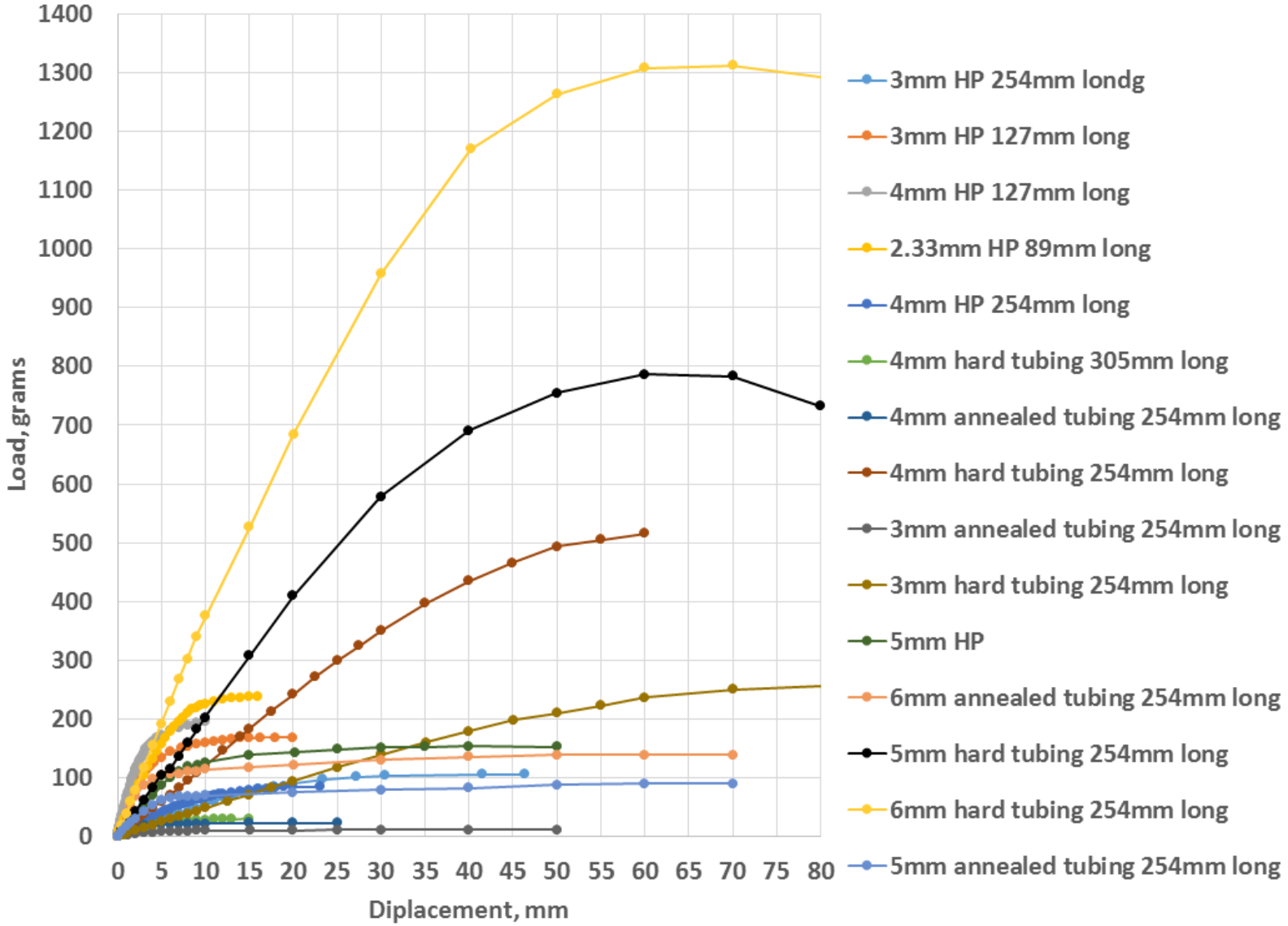


$$I = \frac{\pi(D^4 - d^4)}{64}$$

Measurement Setup



Test Data


1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Load, grams
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
Diplacement, mm
3mm HP 254mm londg
3mm HP 127mm long
4mm HP 127mm long
2.33mm HP 89mm long
4mm HP 254mm long
4mm hard tubing 305mm long
4mm annealed tubing 254mm long
4mm hard tubing 254mm long
3mm annealed tubing 254mm long
3mm hard tubing 254mm long
5mm HP
6mm annealed tubing 254mm long
5mm hard tubing 254mm long
6mm hard tubing 254mm long
5mm annealed tubing 254mm long

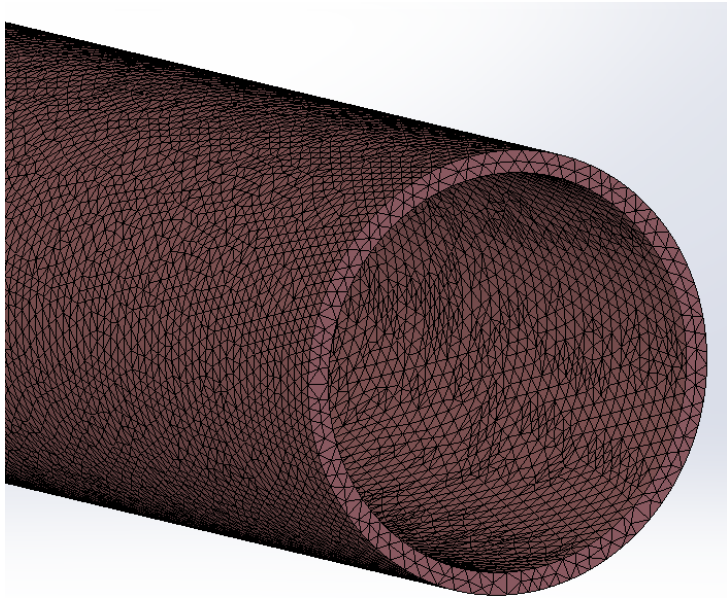
FEA Modeling

- Solid Works Simulation package
  - Solid Works 2015 Premium x64 edition (SP 1.1)

- Boundary conditions:

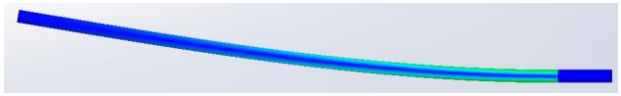
- Mesh

Study name	Static 1 (-Default-)
Mesh type	Solid Mesh
Mesher Used	Curvature based mesh
Jacobian points	4 points
Max Element Size	0.0088498 in
Min Element Size	0.0048498 in
Mesh quality	High
Total nodes	2080642
Total elements	1237467
Maximum Aspect Ratio	5.3611
Percentage of elements with Aspect Ratio < 3	99.8
Percentage of elements with Aspect Ratio > 10	0
% of distorted elements (Jacobian)	0



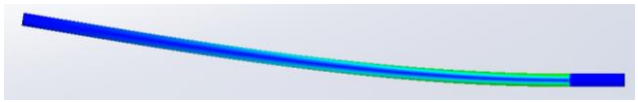
FEA Typical Results (6mm Case)

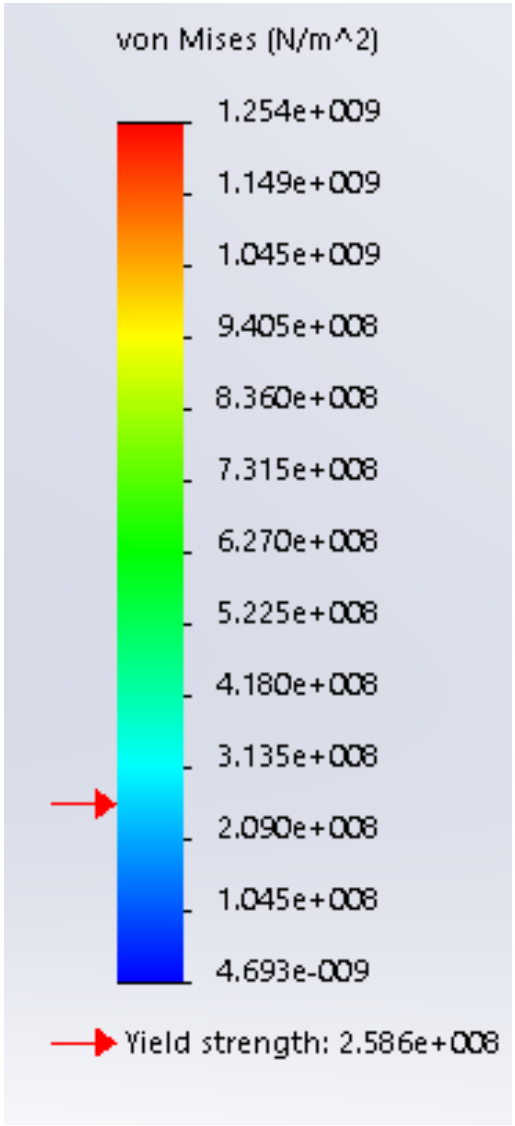
Stress

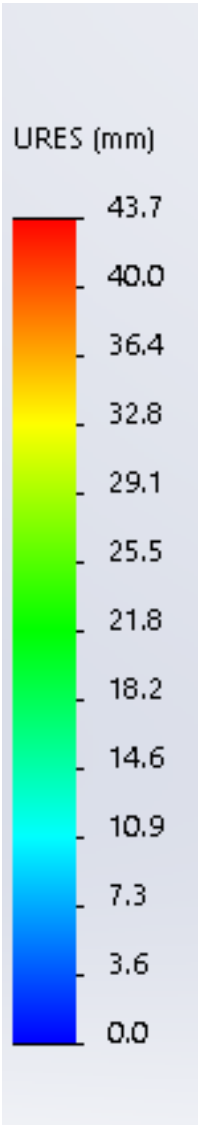


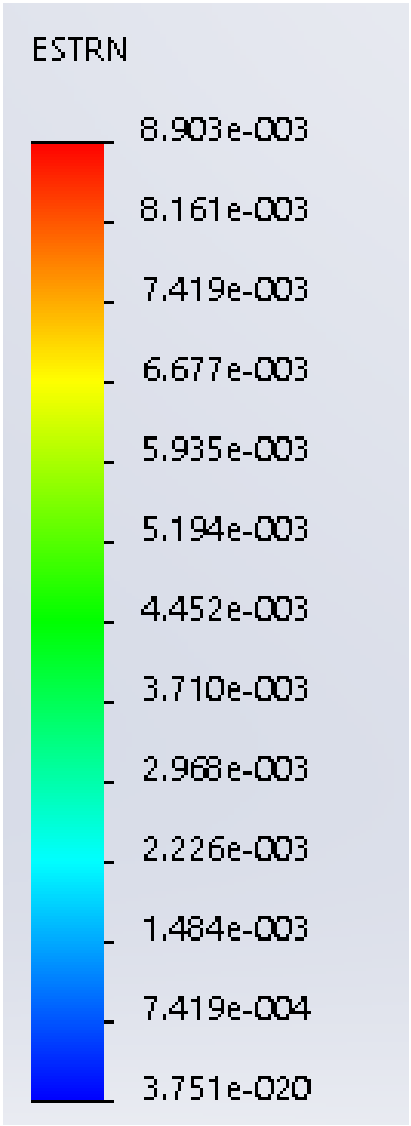
Displacement

Strain

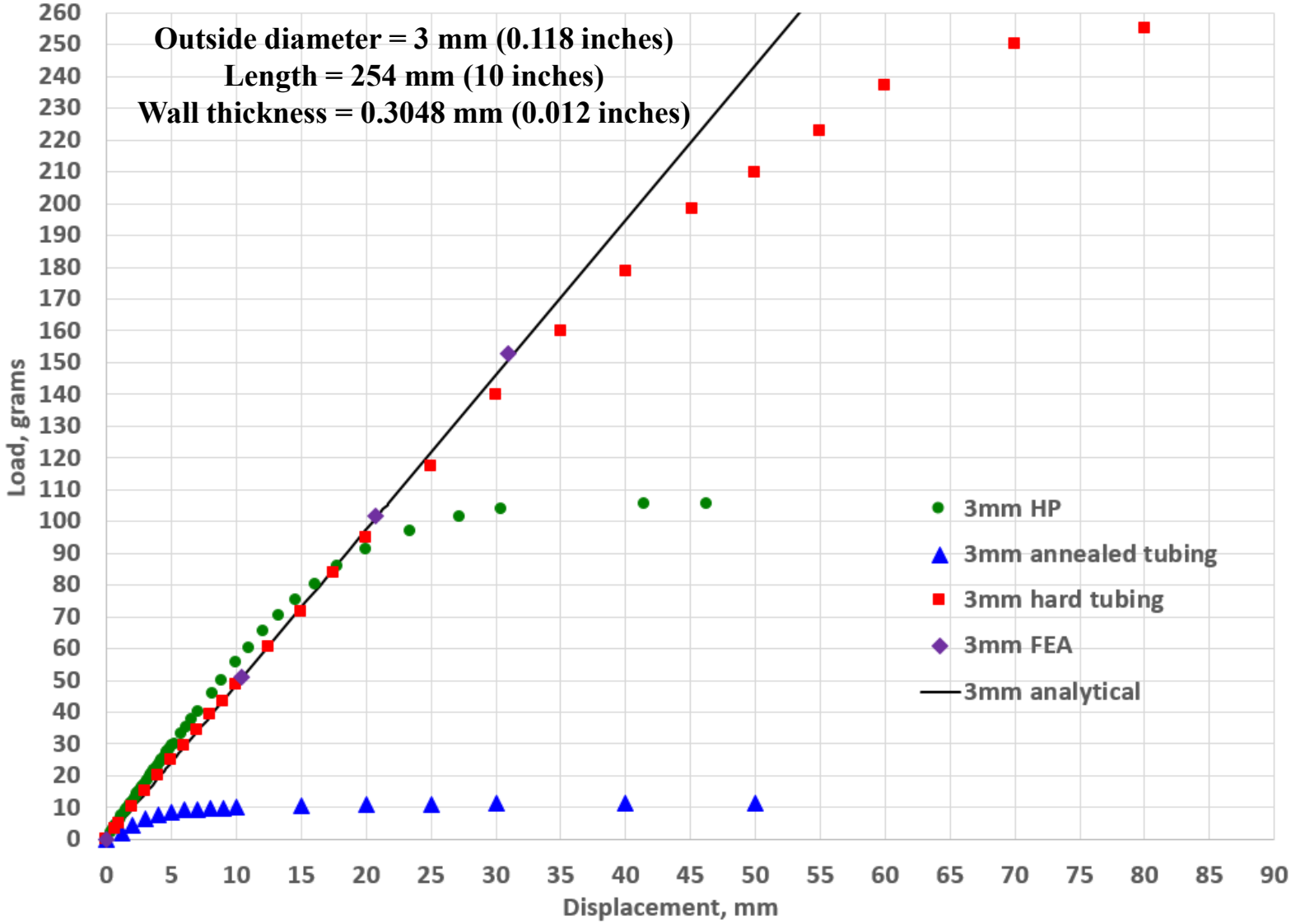




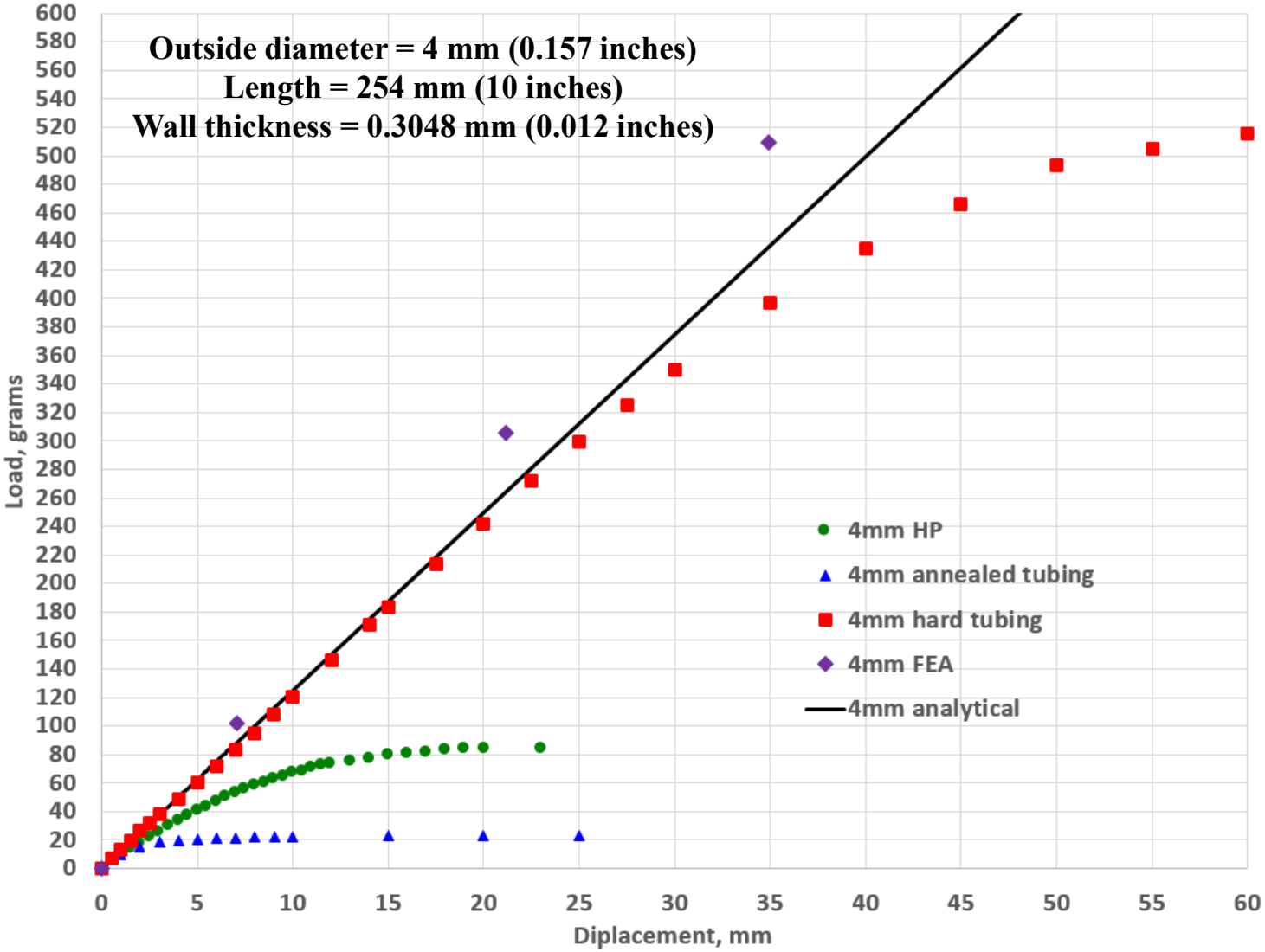




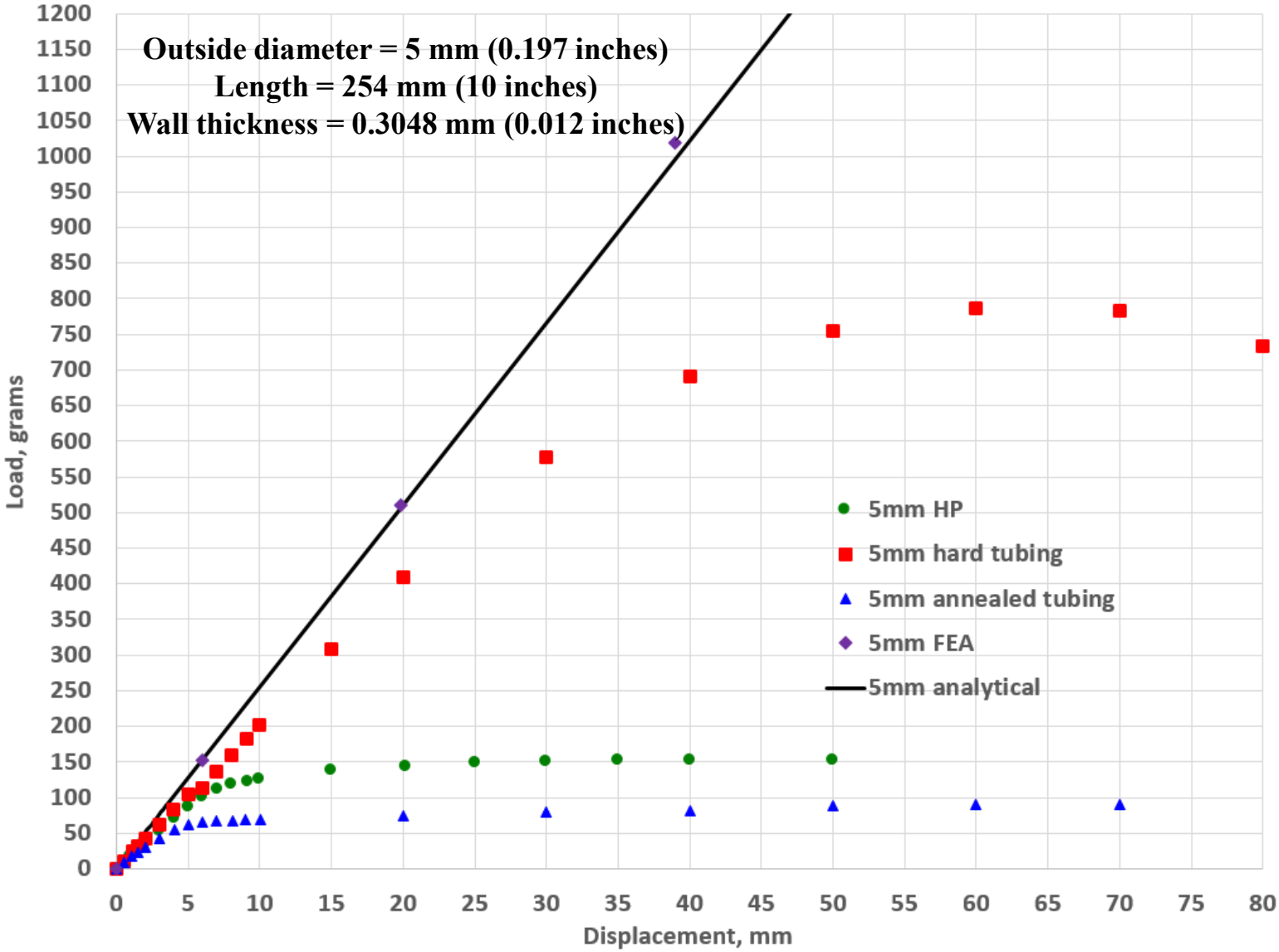
3mm Results


Outside diameter = 3 mm (0.118 inches)
Length = 254 mm (10 inches)
Wall thickness = 0.3048 mm (0.012 inches)
Load, grams
Displacement, mm
3mm HP
3mm annealed tubing
3mm hard tubing
3mm FEA
3mm analytical

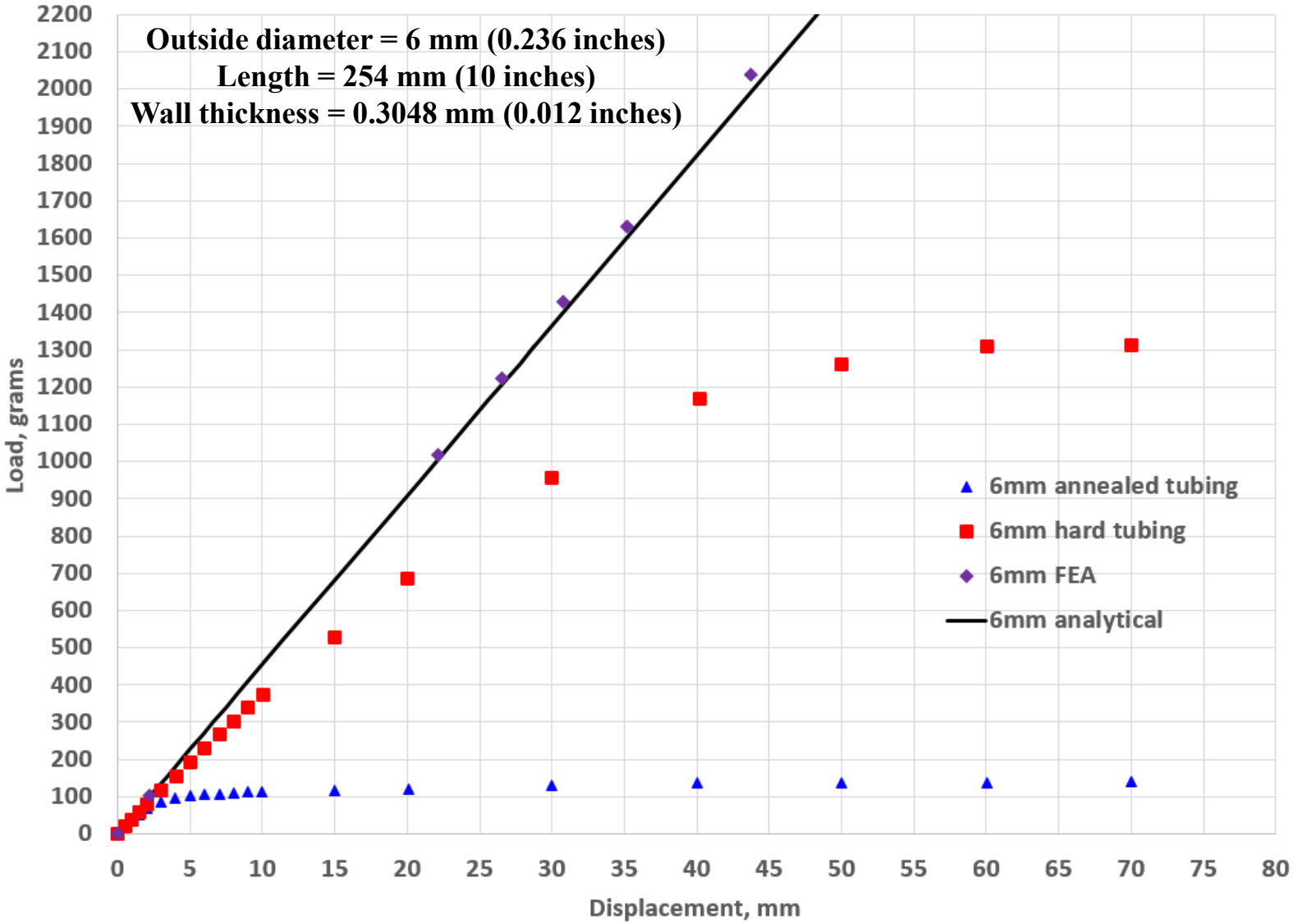
4mm Results


Outside diameter = 4 mm (0.157 inches)
Length = 254 mm (10 inches)
Wall thickness = 0.3048 mm (0.012 inches)
Load, grams
Diplacement, mm
4mm HP
4mm annealed tubing
4mm hard tubing
4mm FEA
4mm analytical

5mm Results


Outside diameter = 5 mm (0.197 inches)
Length = 254 mm (10 inches)
Wall thickness = 0.3048 mm (0.012 inches)
Load, grams
Displacement, mm
5mm HP
5mm hard tubing
5mm annealed tubing
5mm FEA
5mm analytical

6mm Results

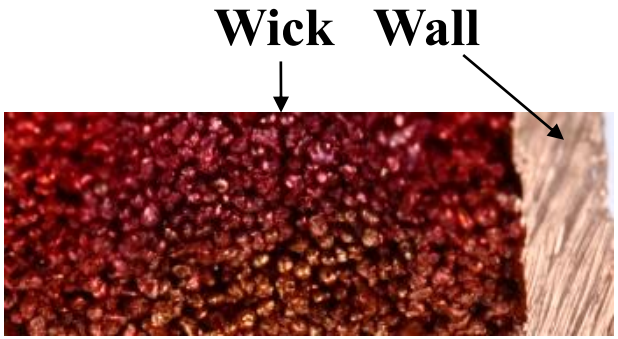

Outside diameter = 6 mm (0.236 inches)
Length = 254 mm (10 inches)
Wall thickness = 0.3048 mm (0.012 inches)
Load, grams
Displacement, mm
6mm annealed tubing
6mm hard tubing
6mm FEA
6mm analytical

Conclusions on Flexibility Investigation

- Annealed copper tubing and HPs have very small elastic region.
- Plastic deformation observed when end displacement exceeds 1% of the HP length.
- Simple analytical formula (slide 3) can be used for prediction of the end displacements when they are small (< 1% of the HP length).
- FEA results are in good agreement with analytical calculations.
- Maximum HP flexibility can be approximated as annealed tubing.
- Work hardening has not been investigated in this study.

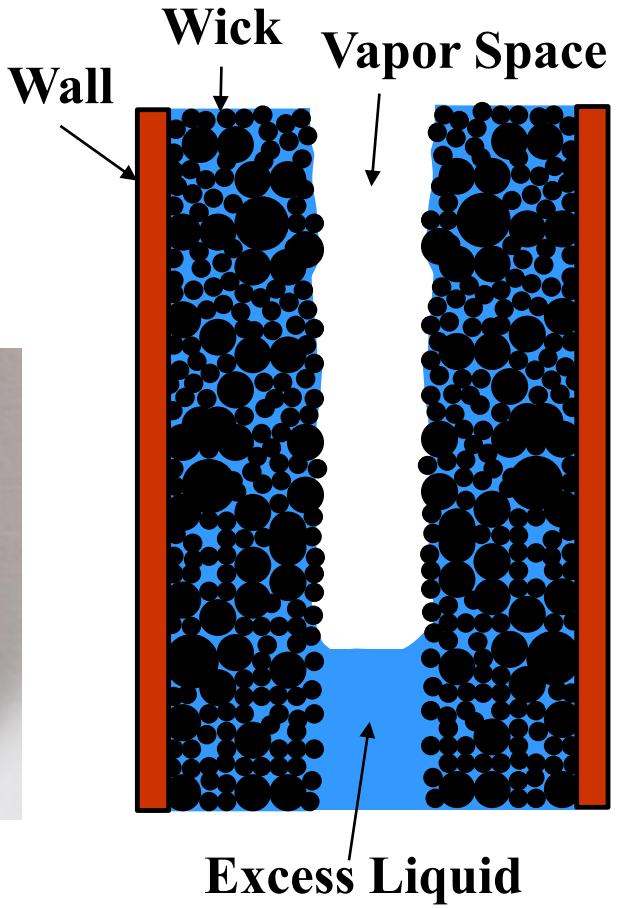
Freeze-Thaw Tolerance of HPs

- Freeze-thaw tolerance of HPs depends on the wick flexibility, proper fluid charge and HP length.



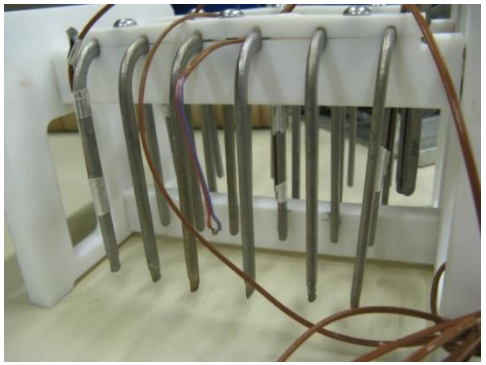
Non-bulged HP

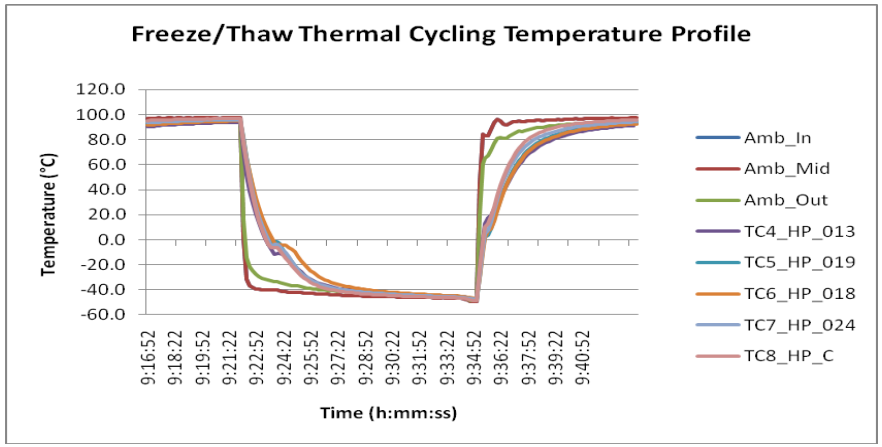
Bulged HP



The Longest Heat Pipe Freeze/Thaw Test

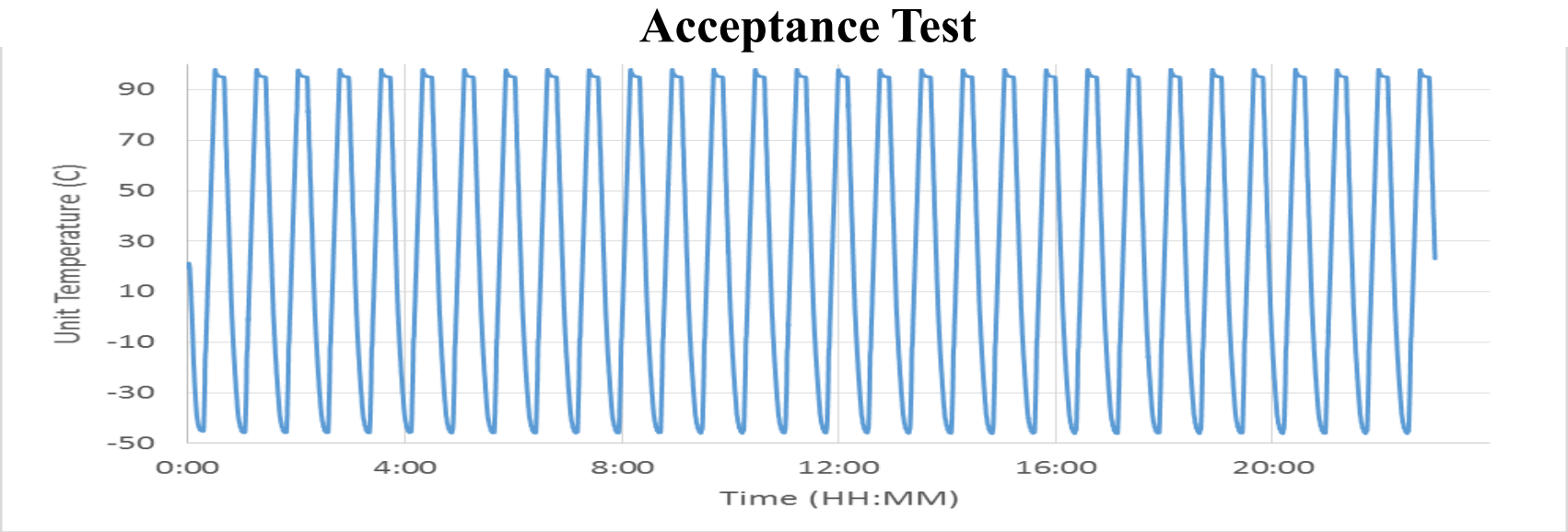
- Copper/Water Heat Pipes
  - U-shaped
  - Bent and Flattened
  - Sintered Powder Metal Wick
  - 1650 Thermal Freeze/ Thaw Cycles
  - -40°C to +100°C
  - 5 Minute Cycle Time





A More Typical Freeze/Thaw Test

- Typical freeze/thaw test
  - Acceptance Test ~ 25 cycles
  - Qualification Test ~ 100 cycles
- Thermal Chamber runs almost non-stop
  - 3.4 freeze/thaw tests per week
  - Common settings
    - 10 cycles, 25 cycles, 100 cycles
    - -15C to +25C, -40C to +90C



Freeze-Thaw Cycling of Copper – Water HPs

- Can be made freeze-thaw tolerant
  - Proper wick sintering
  - Proper fluid charge
  - Static lift height must exceed the vertical HP length in 1G environment
- Thermacore performs an acceptance test on every flight unit.
- Dimensional inspection and thermal performance testing conducted before and after freeze-thaw cycling.